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# (54) Fiducial cup

(57) A fiducial positioning cup (86) has a hemispherical well (92) in its top and a central bore (94) from a bottom of the hemispherical well (92) to a base of the positioning cup (86). The fiducial cup (86) is then attached to the skin (88) of a patient. A needle is passed through the fiducial positioning cup (86) to mark an area of the patient's skin (88) with a tattoo. Fiducials are secured in the fiducial positioning cups (86). Magnetic resonance or other diagnostic images are taken. Once the images are taken, the fiducials and fiducial positioning cups (86) are removed. The tattoo mark remains. The fiducial positioning cups (86) are reattached when a stereotactic procedure is to be performed. The needle is passed through the fiducial cups (86) and a tip of the needle is aligned with the tattooed mark on the patient's skin (88). The fiducial cup (86) is then lowered and centred over the tattooed mark. A stereotactic wand is aligned with the magnetic resonance image by placing a tip of the wand in the fiducial cups (86) and emitting signals. The stereotactic system decodes the signals to identify where the tip of the wand is on the magnetic resonance image.

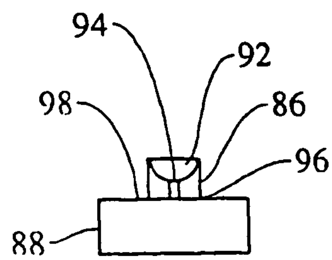


Fig. 5

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**Description**

[0001] The present invention relates to the medical diagnostic and surgical fields. It finds particular application in conjunction with stereotactic surgery and will be described with particular reference thereto. However, it is to be appreciated that the invention will also find application in conjunction with minimally invasive surgery, neurosurgery, neurobiopsy, CT-table needle body biopsy, breast biopsy, endoscopic procedures, orthopedic surgery, other invasive medical procedures, industrial quality control procedures, and the like.

[0002] Three-dimensional diagnostic image data of the brain, spinal cord, and other body portions are produced by CT scanners, magnetic resonance imagers, and other medical diagnostic equipment. These imaging modalities typically provide structural detail with a resolution of one millimetre or better. Various frameless stereotaxy procedures have been developed which take advantage of three-dimensional image data of the patient. These procedures include guided-needle biopsies, shunt placements, craniotomies for lesion or tumour resection, and the like. Another area of frameless stereotaxy procedure which requires extreme accuracy is spinal surgery including screw fixation, fracture decompression, and spinal tumour removal.

[0003] In brain biopsy procedures, for example, surgeons or other medical personnel drill and tap a hole in a patient's skull. Surgeons have come to rely on frameless stereotaxy procedures for placing and orienting the bit of the surgical drill prior to forming the hole in the skull. These procedures require aligning images of fiducials or markers. affixed at three or more spaced points on the patient's body, with known fiducial positions in patient space. The fiducials are spherical markers or small beads that are injected with radiation opaque and magnetic resonance excitable materials and fit within a fiducial positioning cup. Therefore, the fiducials are visible in the imaging medium selected such that they show up as readily identifiable dots in the resultant image data.

[0004] Heretofore. the fiducials have been affixed directly to the patient's body using a glue. Fiducials have also been attached to a patient's skull using screws. However, these methods of attachment have proven undesirable, especially if it is necessary to remove the fiducials for a period of time before they are reattached. Because the imaging modalities discussed above typically provide structural detail with a resolution of a millimetre or better, it is critical that the fiducials be reattached as close as possible to the exact location where they were previously located. Such accuracy is difficult to achieve when using a glue to attach the small, spherical fiducials directly to the patient's body.

[0005] A fiducial cup for a magnetic resonance imaging system for designating a coordinate and trajectory on a subject includes a subject support. A wand defines a tip portion and a pointing axis of the wand. A means determines a position of the wand tip portion and the pointing axis. An image memory stores image data indicative of a three-dimensional region of the portion of the subject which is secured to the subject support means. A selecting means selects data from the three-dimensional image memory. A display converts the selected data from the image memory into human-readable displays. A transform processor transforms a position of the wand tip and pointing axis into a coordinate system of the image data stored in the image memory. At least one fiducial is imaged during generation of the image data disposed at selected subject positions when the three-dimensional image data was acquired such that a locations of the at least one fiducial are identifiable in the three-dimensional image data. The fiducial is supported by a fiducial cup. Each fiducial cup comprises a fiducial receiving surface against which the fiducial is removably mounted and a subject surface that is removably affixed to the subject.

[0006] In accordance with one aspect of the invention. the fiducial receiving surface includes a hemispherical well.

[0007] In accordance with a more limited aspect of the invention, a central bore extends from a bottom of the hemispherical well to the subject surface.

[0008] In accordance with another aspect of the invention, the fiducial receiving surface has a spherical segment well of a common radius with the wand tip for rotatably receiving the wand tip therein.

[0009] In accordance with another aspect of the invention, an adhesive secures the subject surface to the subject and a fiducial to the fiducial surface.

[0010] In accordance with a more limited aspect of the invention. the wand has a concave spherical segment tip and a spherical fiducial is secured to the fiducial surface. The fiducial and the concave tip have a common radius.

[0011] One way of carrying out the invention will now be described in detail, by way of example, with reference to the accompanying drawings, in which:

FIGURE 1 is a perspective view of an operating room in which the present invention is deployed;

FIGURE 2 is a block diagram of the image data manipulation of the present system of FIGURE 1;

FIGURE 3 illustrates the wand;

FIGURE 4 is illustrative of a preferred coordinate transform between the coordinate system of the data and the patient;

FIGURE 5 illustrates a fiducial positioning cup on the surface of a patients skin;

FIGURE 6 illustrates the steps of positioning and repositioning a fiducial positioning cup and a fidu-

cial:

FIGURE 7 illustrates a needle inserted through the fiducial cup for tattooing a mark in the patient's skin;

FIGURE 8 illustrates a fiducial positioning cup having a tattooed mark below the bore;

FIGURE 9 illustrates the fiducial inserted into the fiducial positioning cup:

FIGURE 10 illustrates the needle aligned with the tattooed mark for repositioning the fiducial cup;

FIGURE 11 illustrates the repositioned fiducial cup held in place by adhesive;

FIGURE 12 illustrates the fiducial cup held in place by a screw;

FIGURE 13 illustrates a convex hemispherical wand tip placed in the fiducial cup; and

FIGURE 14 illustrates a concave hemispherical wand tip placed on a spherical fiducial held in the fiducial cup.

[0012] With reference to FIGURE 1, a subject, such as a human patient is received on an operating table or other subject support **10** and appropriately positioned within the operating room. A frame **12** is mounted in a fixed relationship to the patient such that it is precisely positioned within the subject or subject support coordinate system. In the illustrated embodiment. the frame **12** is mounted to the patient support **10**. Mounting the frame **12** to the patient support **10** permits the support to be turned, raised, lowered, wheeled to another location, or the like. without altering the patient coordinate system. Alternatively, the support may be mounted to a pole or other stationary support, the ceiling of the room, or the like. The frame **12** supports a plurality of receivers **14** such as microphones, radio frequency receivers, light sensitive diodes, other light sensitive receivers, and the like mounted at fixed, known locations thereon. A securing means. such as a head clamp **16**, securely positions a portion of the subject into the frame of reference of the frame **12**.

[0013] With continuing reference to FIGURE 1 and further reference to FIGURE 2, an operator console **18** houses a computer system **22** and a data memory **24**. The stored three-dimensional image data preferably contains a video pixel value for each voxel or point in a three-dimensional rectangular grid of points, e.g. a 256 x 256 x 256 grid. Selectable orthogonal and other oblique planes of the data can readily be withdrawn for display from the three-dimensional memory **24** by a plane or slice selector **26** using conventional technology.

[0014] For example, the pixel values which lie on a selected axial, sagittal, coronal, and oblique planes are copied into corresponding image memories **28a, 28b, 28c, 28d**. A video processor **32** converts the two-dimensional digital image representations from one or more of the image memories **28** into appropriate signals for display on video monitors **34** or other appropriate image displays.

[0015] With continuing reference to FIGURE 1 and further reference to FIGURE 3, a wand **36**, formed of suitable material such as metal, has a hemispherical tip portion at a proximal end **42**. The tip is connected to a portion extending along a pointing axis **44** of the wand. In the illustrated embodiment, a first emitter **46** is located at $(x_1, y_1, z_1)$ along the axis **44** a fixed known distance $\ell_1$ from the tip **42**. The second emitter **48** is at $(x_1+\Delta x_2, y_1+\Delta y_2, z_1+\Delta z_2)$, where $\Delta x_2$, $\Delta y_2$ and $\Delta z_2$ represent constant values based on the geometry of the second emitter **48** relative to the tip **42**. The third emitter **52** is at $(x_1+\Delta x_3, y_1+\Delta y_3, z_1+\Delta z_3)$, where $\Delta x_3$, $\Delta y_3$ and $\Delta z_3$ represent constant values based on the geometry of the third emitter **52** relative to the tip **42**.

[0016] Emitters **46, 48, 52** emit infra-red positioning signals used by a locator system **54** to locate a coordinate and trajectory of the wand. Infra-red signals are received from each of the emitters at the receivers. The three infra-red signals received by each receiver are used to calculate the axis **44** and the location of the tip. The plane or slice selector **26** (FIGURE 2) selects patient image planes based on the coordinate and trajectory located. It is to be appreciated that more than three emitters may be mounted on the wand to provide additional positioning signals to be used by a locator system to locate the coordinate and trajectory of the wand. Furthermore, it is to be understood that the emitters **46, 48, 52** may also emit spark or radio frequency signals which are received by the receivers **14**.

[0017] With reference to FIGURE 4. before the wand **36** can be used to locate a proper coordinate and trajectory for a surgical tool such as a drill, the patient space or coordinate system (x, y, z) is aligned with the image space or coordinate system (x', y', z') stored in memory. Aligning the spaces begins with referencing known positions or points **78** in the patient space with the wand tip **42**. For example, the tip of the wand may be referenced to three fiducials, tattoo marks, or characteristic physical anatomy, e.g. the tips of the spinous and traverse processes. These known points **78** are compared with corresponding position of pixels **82** in the image space.

[0018] With reference to FIGURES 5 and 6, a positioning cup **86** is placed on the surface of the patient's skin **88** in a step A. Each positioning cup **86** is a base into which one of the fiducials **84** is attached. Furthermore, the cups **86** each have a hemispherical (or slightly less than a half sphere) well **92** in its top and a central bore **94** from the bottom of the hemisphere **92** to a base **96** of the cup. The fiducial positioning cup **86** is preferably invisible to the imaging medium selected such that

it does not show up in the resultant image data. Preferably, the positioning cup **86** is glued to the patient's skin **88**.

**[0019]** As described above, image data, including the fiducials affixed at the three or more spaced points on the patient's body, is aligned with the patient space containing physical fiducials **84**. Therefore, the fiducials **84** and the positioning cups **86** ideally remain fixed in place during the time interval between which the image data is gathered and the stereotaxy procedure is performed. However, because this time interval may be several hours, or even days, the cups are not always kept in place. Rather, they are removed and reattached later.

**[0020]** To facilitate accurately repositioning the cups **86**. FIGURES 6 and 7 illustrate that in a step **B**, before the fiducials **84** are attached in the cup or after the fiducials are removed from the cup, a tattoo needle **110** is inserted through the bore **94** to place a small tattoo mark **112** (see FIGURE 8) on the patient's skin **88**. Thereafter, in a step **C** the fiducial **84** is affixed to the support (see FIGURES 6 and 9), preferably using adhesive, and the image data is gathered. After the image data is obtained, the positioning cups **86** are removed in a step **D** of FIGURE 6. The tattoo marks **112**, however, remain visible.

**[0021]** Before the stereotaxy procedure is performed, the three cups **86** are re-affixed to the patient's skin **88** in a step **E** of FIGURE 6. With reference to FIGURE 10, the needle **110** is inserted through the bore **94** in each support **86** and into the respective tattooed spot **112**. The support **86** is then dropped down the needle **110** and accurately positioned so that it is centred on the tattooed spot **112**. Preferably, as illustrated in FIGURE 11, the supports **86** are then adhered to the patient's skin. Alternatively, as illustrated in FIGURE 12, a surgical screw **114** is inserted into the respective bore to affix the fiducial support **86** to the patient's skull or other boney plate.

**[0022]** As already discussed above in reference to FIGURE 4, the positions of the three fiducials **84** are compared with the relative position of the images **82** of the centroids of the fiducials in the image space. Actuating the emitters while the tip of the wand is touching each of its characteristic patient space points (x. y, z) defines these points electronically. Like coordinates (x', y', z') of the image pixels **82** are defined electronically from the electronic image and compared to the patient space coordinates (x, y, z). As illustrated in FIGURE 13. the wand **36** preferably has a convex hemispherical end which is inserted into each of the respective fiducial supports **86**. After the emitters are actuated, a virtual tip **116** of the wand is then correlated with a centroid of the fiducial in the electronic image. The virtual tip is defined at the geometric centre of the sphere defined by the hemispherical tip. Because the hemispherical tip **42** of the wand is the same radius as the fiducial **84**, the virtual tip **116** of the wand is located at the centroid of the fiducial, regardless of the wand's trajectory.

**[0023]** As illustrated in FIGURE 14, in an alternative embodiment, the wand **36** has a concave partial spherical in its tip **42** which contacts the spherical surface of the fiducial **84**. In this embodiment, the virtual tip **116'** of the wand is calculated to be the geometric centre of the partial spherical surface which falls at the centroid of the fiducial when the tip is against the fiducial. In either of the two embodiments, the virtual tip of the wand is offset from the physical tip.

**[0024]** Having aligned the image and patient spaces, a wand with its physical and virtual tips aligned can be used to identify the entry coordinate and trajectory at which the surgical tool will be applied to the patient. The surgeon manoeuvres the wand to a proposed trajectory and actuates the emitters. Signals from the emitters are used to calculate the trajectory and the end point of the wand. The trajectory and end point are displayed on the monitor superimposed on the three-dimensional image or selected image plane(s).

**[0025]** By viewing the display. the surgeon identifies the location of the wand tip with respect to anatomic structure, and the trajectory of the bore. If the trajectory is unsatisfactory, the wand is repositioned and its new trajectory determined and evaluated.

**[0026]** One advantage of the above described embodiment is that it improves the accuracy of positioning and repositioning of fiducials. Another advantage is that it improves the accuracy with which the diagnostic images are aligned with the patient. Another advantage is that the fiducials are securely held within the fiducial positioning cups. Another advantage is that the fiducial positioning cups include a larger surface area, relative to the fiducials, for contacting the patient's skin.

**[0027]** The invention has been described with reference to the preferred embodiment. Obviously, modifications and alterations will occur to others upon reading and understanding the preceding detailed description. It is intended that the invention be construed as including all such modifications and alterations insofar as they come within the scope of the appended claims or the equivalents thereof.

**Claims**

1. A fiducial cup (86) for designating a coordinate and trajectory on a subject for use in association with a magnetic resonance imaging system, the fiducial cup comprising: a fiducial receiving surface (92) against which a fiducial (84) is removably mounted; and a subject surface (96) that is removably affixable to the subject.

2. A fiducial cup as claimed in claim 1, wherein the fiducial receiving surface (92) includes a hemispherical well.

3. A fiducial cup as claimed in claim 1 or claim 2, wherein the fiducial receiving surface (92) has a

spherical segment well of a common radius with a wand tip (42) for rotatably receiving the wand tip (42) therein.

4. A fiducial cup as claimed in any one of claims 1 to 3, further including: a central bore (94) extending from a bottom of the hemispherical well (92) to the subject surface (88).

5. A fiducial cup as claimed in any one of claims 1 to 4, further including: an adhesive which secures the subject surface (96) to the subject and the fiducial (84) to the fiducial surface (92).

6. A fiducial cup as claimed in any one of claims 1 to 5, including a spherical fiducial (84) secured to the fiducial surface (92), the fiducial (84) having a common radius with the concave spherical segment tip of a wand (36).

7. An imaging system including a fiducial cup as claimed in any one of claims 1 to 6, the imaging system including a subject support (10), a wand (36) defining a tip portion (42) and a pointing axis (44) of the wand (36), means (14, 46, 48, 54) for determining a position of the wand tip portion (42) and the pointing axis (94), an image memory (28) for storing image data indicative of a three-dimensional region of the portion of the subject which is secured to the subject support means (10), a selecting means (26) for selecting data from the three-dimensional image memory (28), a display (34) for converting the selected data from the image memory (28) into human-readable displays, a transform processor for transforming a position of the wand tip (42) and pointing axis into a coordinate system of the image data stored in the image memory (28), at least one fiducial (84) which was imaged during generation of the image data disposed at selected subject positions when the three-dimensional image data was acquired such that locations of the at least one fiducial (84) are identifiable in the three-dimensional image data, the fiducial (84) being supported by the fiducial cup.

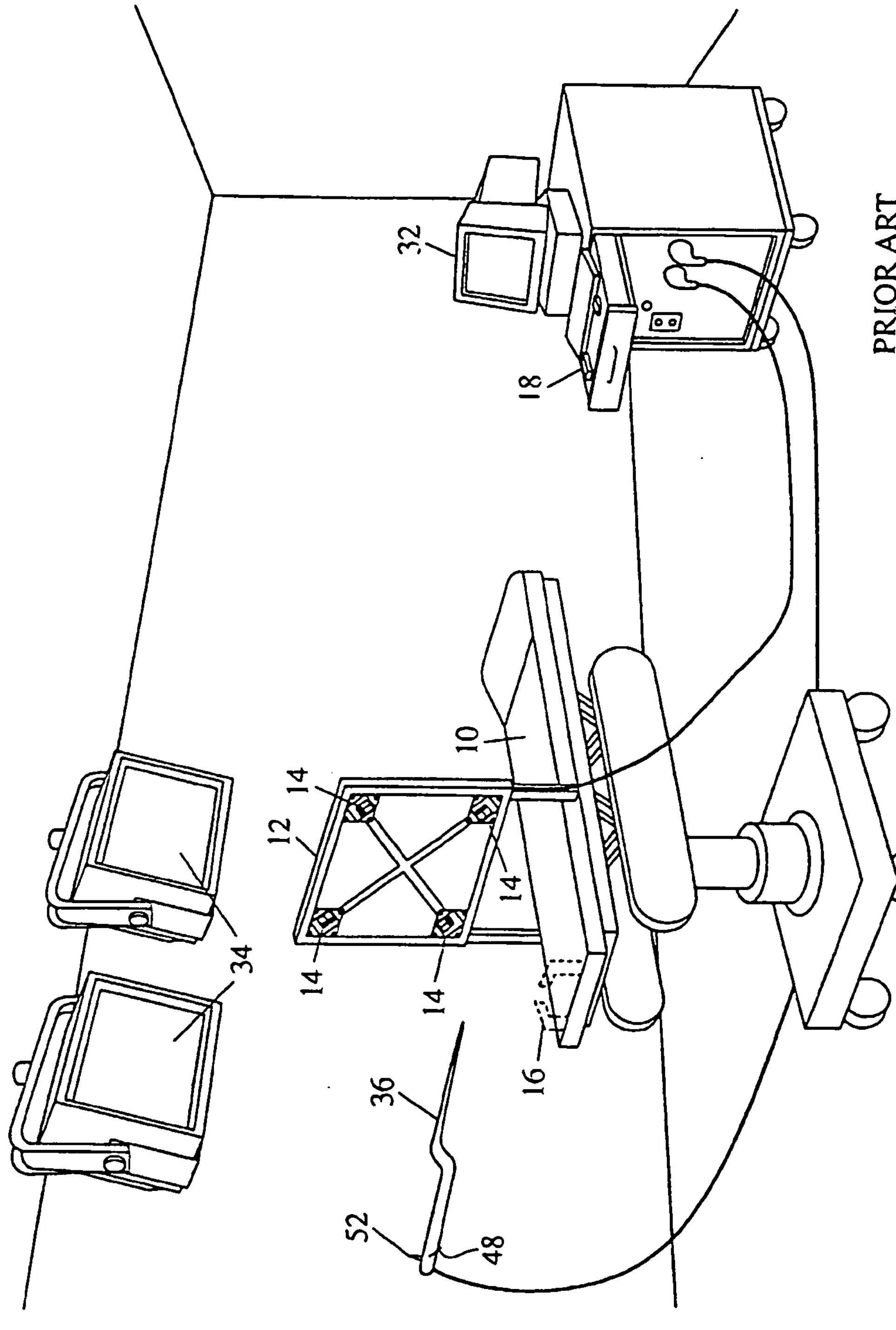
8. An imaging system as claimed in claim 7, including a magnetic resonance imaging system for imaging the portion of the subject which is secured to the subject support means.

9. A method of correlating locations on a subject with a diagnostic image. the method comprising: a) identifying a location on the subject: b) attaching a fiducial positioning cup (86) to the location on the subject; c) securing a fiducial (84) to fiducial positioning cup (86); d) performing a diagnostic imaging procedure to generate a diagnostic image, the fiducial (84) being identifiable in the diagnostic image; and e) removing (D) the fiducial (84) from the cup.

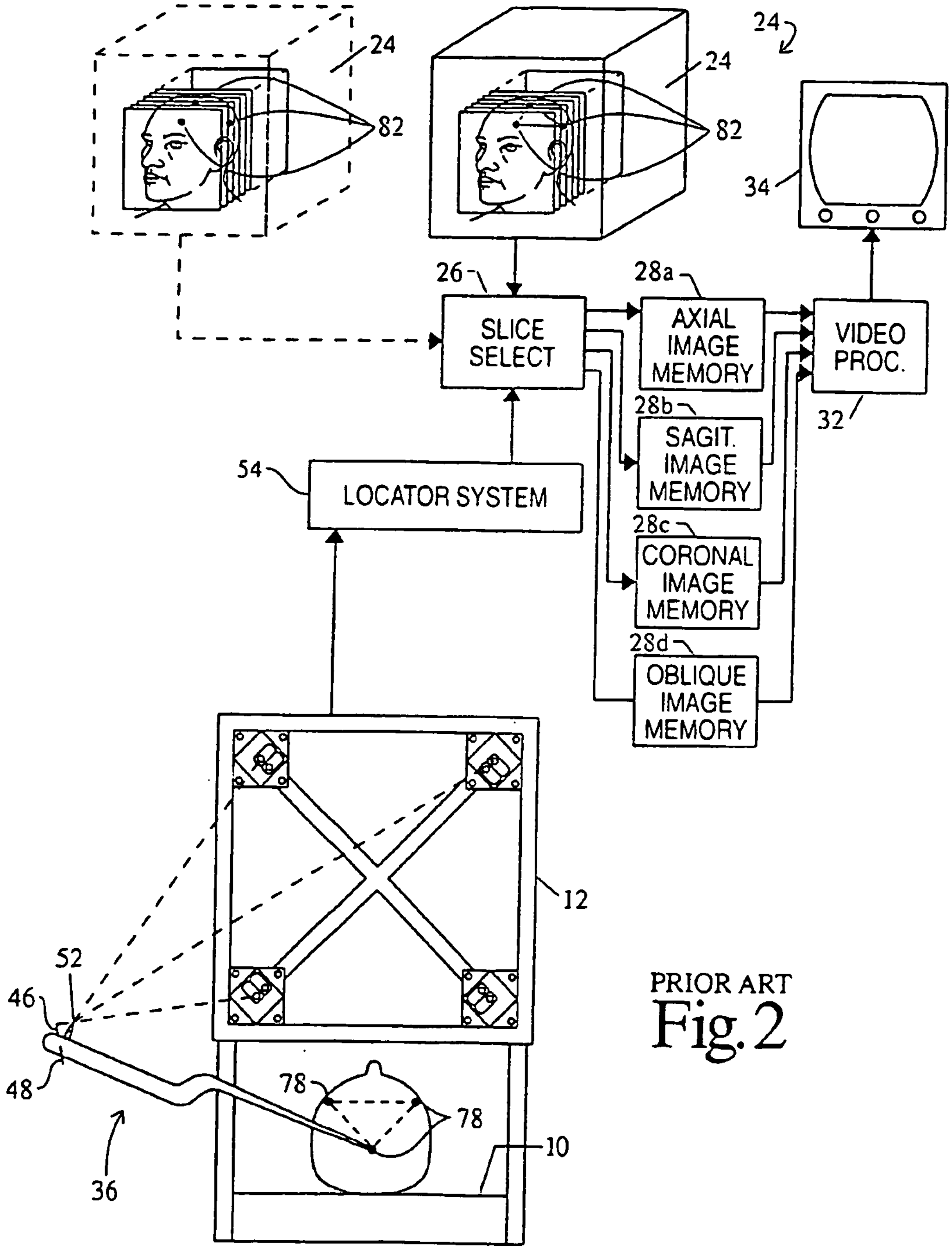
10. A method as claimed in claim 9, wherein the fiducial positioning cup (86) includes a central bore (94) and further including: marking (B) the patient through the central bore (94) to provide a reference for re-positioning the fiducial positioning cup (86).

11. A method as claimed in claim 9 or claim 10, wherein the patient is marked to identify locations at which the fiducial positioning cups (86) are to be secured and further including: inserting a needle (110) through a central bore (94) of a fiducial positioning cup (86) to be secured; placing a tip of the needle (110) on the mark (112) on the subject; and sliding the fiducial positioning cup (86) along the needle (110) and securing the fiducial positioning cup (86) to the subject.

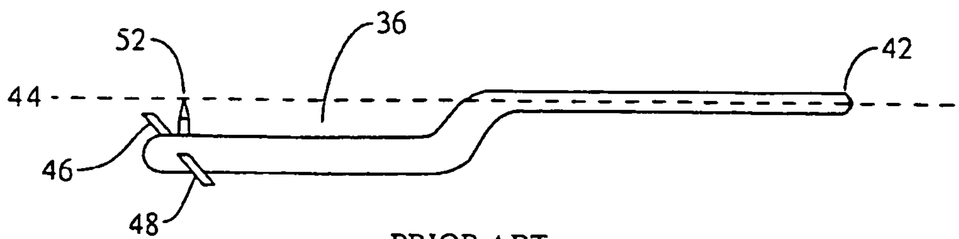
12. A method as claimed in any one of claims 9 to 11, further including: touching a tip (42) of a stereotactic tool (36) which is contoured (i) to receive a fiducial (84) or (ii) to be received in the cup (86) of each fiducial (84); and correlating physical locations of the stereotactic pointer (36) with the diagnostic images.



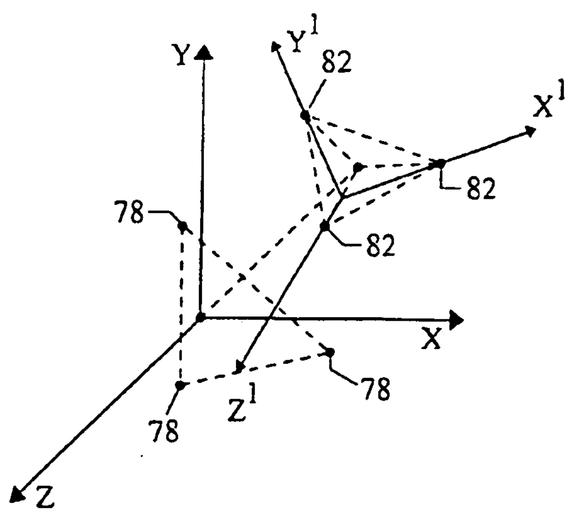

PRIOR ART
Fig. 1




PRIOR ART
Fig. 2




PRIOR ART
Fig.3




PRIOR ART
Fig.4

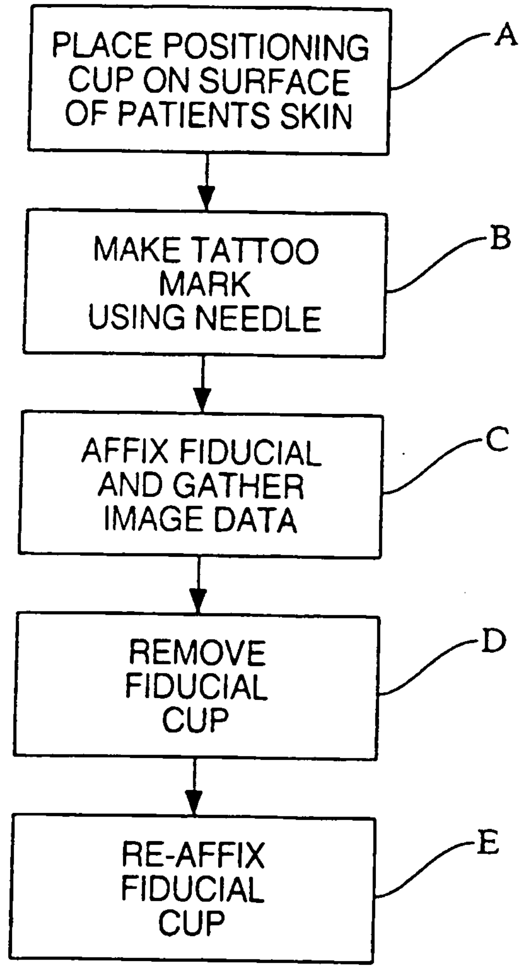

PLACE POSITIONING CUP ON SURFACE OF PATIENTS SKIN
A
MAKE TATTOO MARK USING NEEDLE
B
AFFIX FIDUCIAL AND GATHER IMAGE DATA
C
REMOVE FIDUCIAL CUP
D
RE-AFFIX FIDUCIAL CUP
E

Fig. 6

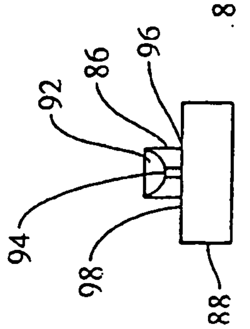



Fig.5

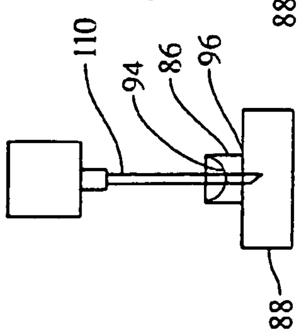



Fig.7

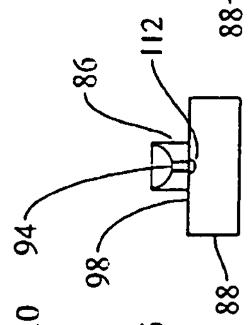



Fig.8

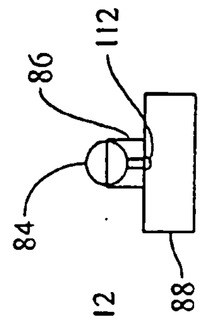



Fig.9

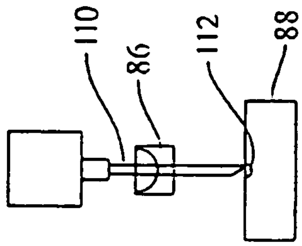



Fig.10

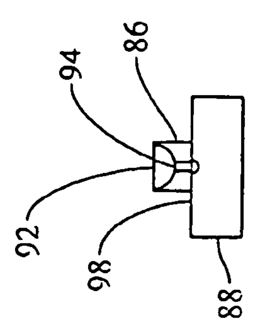



Fig.11

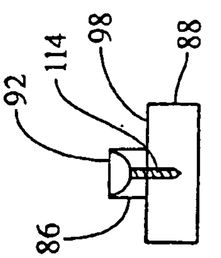



Fig.12

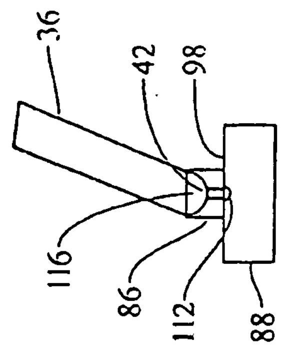



Fig.13

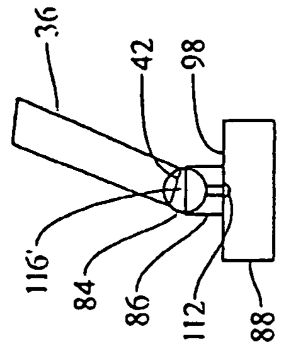



Fig.14